Building ponds with animal power in the Ethiopian highlands

A manual

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and Frank Anderson

International Livestock Centre for Africa

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PREFACE

A safe, adequate and accessible water supply is a prerequisite for socio-economic development. The fact that the United Nations has designated the period 1981–1990 as the International Drinking Water Supply and Sanitation Decade highlights the growing awareness throughout the world of the need for improved water supplies. The current drought and famine throughout much of Africa also emphasise the need for immediate and widespread water conservation.

Many people in Ethiopia and throughout the Third World lack access to adequate water supplies for household consumption or for livestock. Water shortages are particularly acute for small communities in rural areas which depend on the natural recharge of springs and wells. Frequently such supplies are inadequate during the dry season. In locations that have suitable topography and rainfall characteristics the problem can be alleviated by building ponds to trap surface runoff during the rainy season for use later in the year.

An appropriate method of excavating such ponds in rural areas of Ethiopia is through the use of draught animals. Suitable equipment and techniques for pond excavation using draught oxen have been designed and tested by ILCA. Preliminary results have shown that there are no major technical constraints, but organisation of the participating farmers is critical in ensuring the success of such work.

This manual provides information and guidance to assist those in Ethiopia involved in the excavation of ponds using animal power. It is based on ILCA's experience in pond construction at its Debre Berhan research station, and on the experiences of two Peasant Associations (PAs) in the area. This first edition is intended to test the usefulness of the manual under field conditions. Comments from users would be appreciated. The manual will be updated as more experience is gained.

It is written for development agents (DAs) appointed by the Ministry of Agriculture to provide technical assistance and guidance to the Peasant Associations. Theoretical explanations are kept to a minimum. Appendices and references are included to give more detailed practical information.

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1. INTRODUCTION

1.1 The concept

Water is a scarce resource in many parts of rural Ethiopia. Both people and their livestock commonly travel long distances daily to obtain the water they need. Much time and energy is expended during daily trekking to distant water supplies. As a result animals lose condition and their productivity is reduced. Existing water supplies can be supplemented by improving water collection at spring sites, by constructing wells to tap groundwater supplies, or by harvesting runoff water in excavated ponds or dams[1]. Constructing ponds or dams using either manual labour or heavy earth-moving machinery may not be appropriate in rural areas because these methods are either too labour intensive or very expensive. However, a technique has recently been developed for excavating ponds using ox-drawn scoops. Harvesting runoff water may now be a viable means of improving water supplies in rural areas of Ethiopia, as this is a low-cost technique within the means of the local population.

The pond technology should be readily accepted by farming communities for many reasons. First, and most importantly, it is directed towards solving a problem of primary concern to rural dwellers; second, it requires little capital expenditure and makes minimal demands on the labour of individuals (since the work load can be shared by all the members of a Peasant Association); and third, the manufacture of scoops and the extension skills necessary to design and supervise pond excavation are well within the capacity of Ethiopia at this stage of its development.

The use of draught animals for constructing ponds could be an effective way of improving water supplies in large areas of Ethiopia. The provision of ponds for water storage could contribute substantially to agricultural development by saving time and energy in the collection of water, by reducing the incidence of water-related diseases and by increasing livestock productivity.

The major contribution of cattle to agricultural production in the Ethiopian highlands (where 70% of the country's cattle are found) is through the draught power provided by oxen. A typical farmer uses oxen for 450 pair hours per year for cultivation and threshing (Gryseels and Anderson, 1983). Cultivation is carried out at some stage between April and July, while threshing takes place between November and January. Animal-drawn scoops could thus be used for pond excavation during periods when oxen are underutilised. Draught power for pulling the scoops could be provided by camels or equines in

[1] A pond is an excavated hole in the ground in which water is stored, whereas a dam implies the storage of water above ground behind an embankment.

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areas where work oxen are not available. However, the scoop and harness would have to be modified according to the type of animal used.

Satisfactory transfer of this technology will require full participation by the Peasant Associations. The ability of a PA to excavate enough ponds of adequate capacity to supply users' needs will depend on the number of working animals that can be used, the amount of feed available, and the suitability of the working schedule in both social and technical terms. The selection of pond sites and the management of completed ponds are also of paramount importance if technology transfer is to be successful.

1.2 Limitations

The use of animal-drawn scoops for excavating ponds of the desired capacities will encounter problems unless certain conditions are fulfilled. The prime consideration is careful selection of the pond site, which is critical for the success of the project. It is also important that the work oxen are well organised to ensure that the maximum output is achieved with the minimum expenditure of human and animal labour. Poor organisation of the participants, or loss of interest in the project, will have a major negative impact on the progress of pond excavation.

The availability of work oxen in the area may be a limitation while a scarcity of feed resources will also hinder the work. If the animals lose condition due to inadequate feeding, the farmers will be reluctant to use them for excavation work. It is also important that sufficient oxen are available to allow work rotation to be followed. In this way the frequency of work by each oxen pair can be limited and the effect on the existing farming system will be minimal.

Before commencing excavation with the scoops proper training of participants and their oxen is essential in order to attain high work efficiency. Excavation should start as soon as possible after the rains when the soil moisture content is optimal for such work. If it is started at a later date when the soil is already dry and difficult to break, the rate of excavation will be dramatically reduced. Similarly, if work is attempted when the soil is very wet, progress will be slow.

Another important consideration is the immediate maintenance of any scoops that are damaged during the working period. If repairs are delayed, the number of operational scoops will be reduced and consequently the overall work rate will decrease.

Provided that all these considerations are taken into account in the design and execution of pond excavation, no major problems are expected.

2. ASSESSMENT OF WATER NEEDS

2.1 Information needed from the Peasant Association

When the need for an improved water supply has been expressed by a PA, a preliminary survey should be conducted. Information regarding the existing water supply must be collected to establish the extent of water shortages, and to ensure that the PA is sufficiently interested to participate fully in pond construction. The potential use of the stored water must be clearly established before selecting the pond site. The amount of available labour and the water requirements of the community must also be known in order to determine a suitable pond size. Information required from the PA is outlined below:

- Whether there is sufficient water for domestic purposes and/or for watering livestock in the area.
- The frequency, degree and duration of water shortages.

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- The main problem in obtaining water (distance to source, water quality or other factors).
- Whether the PA is willing to make land available for a pond (and a protected enclosure immediately upstream of the pond) and to participate fully in pond construction.
- The number of households, the average number of people per household, and the number and type of animals per household within the PA. This will give the number of potential users of the pond(s) and hence the required capacity.
- The amount of labour – both human and animal – that will be available to participate in pond construction. This will be used to determine the number of oxen-pairs working each day and hence the size of the pond that can be excavated in a given time.
- The purposes for which the stored water will be used – for domestic purposes or for livestock watering, or both. Where the water is to be used for household purposes and/or livestock watering the pond should be located as near as possible to the majority of households and grazing areas.

2.2 Estimated water demand

The required capacity of ponds to be constructed depends on the water requirements of potential users (maximum demand and fluctuations in demand during the year), and the expected water losses by evaporation and seepage. The amount of loss by evaporation is directly related to the local climate while seepage losses are related to soil type and, to a lesser extent, to pond design. The pond size required depends on the anticipated use of the stored water – for instance for both domestic purposes and livestock watering. Required pond capacity is also influenced by the period of time for which the water is to be made available. Finally, the number of ponds to be made in an area will determine the required capacity of each pond.

A good estimate of required pond dimensions and capacities must be made to ensure that the amount of water needed by the community is conserved with the minimum expenditure of human and animal labour. Estimation of the water requirement of a community can be based directly on the number of people and their livestock. The number of people in an area is generally fairly stable and will increase only slowly over time, whereas the number of animals may fluctuate more sharply. Environmental factors, such as the occurrence of drought, may have a significant effect on both human and livestock numbers. However, such changes are unpredictable.

Human water consumption varies considerably according to the availability of water and the standard of living of the people. Depending on the climate and work load, between 3 and 10 litres of water per day are essential to meet a person's basic drinking and food preparation requirements. The amount of water used for other purposes varies widely, but much larger quantities are needed for personal hygiene, cleaning of cooking utensils and laundry. A good water supply, combined with proper sanitation, helps to reduce the incidence of diseases.

In Ethiopia, human water consumption varies widely. It ranges from a low of 5 litres per caput per day (l/c/d) for some rural communities, to a high of 120 l/c/d for urban dwellers with more sophisticated water facilities (Teka, 1982). Average rural consumption in Ethiopia in 1973 was estimated as 15 l/c/d (Ministry of the Interior, 1973). This figure is unlikely to be exceeded where water has to be carried.

The calculation of future human demand should take into account population growth and the increased per caput use which will result from improved supplies. A suitable design consumption for the

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human population in rural areas of Ethiopia is 25 l/c/d.

Livestock require 20–30 litres per tropical livestock unit (TLU[2]) per day (EWRA, 1976; Hofkes, 1983). Further details of human and livestock water requirements are given in Table 1. These values are indicative but, as each rural community will differ in use patterns, where possible a field survey should be made to assess water use. Per caput daily water use data can be used to make a rough estimate of a community's water demand, although per household water use may be more accurate since much of the water is shared by members of a family.

Table 1. *Typical water demand for various types of consumer.*

Consumer	Water requirement (l/c/d)
Human use	
Communal source > 1000 m distant	5–10
Communal source 500–1000 m distant	10–15
Communal source < 250 m distant	15–30
Private connections	30–50
Livestock use	
Cattle	25–35
Horses, donkeys and mules	20–25
Sheep and goats	5–15
Pigs	10–15
Poultry (l/100/day)	15–25

Sources: Hofkes (1983); Teka (1982).

[2] One TLU is equivalent to 250 kg liveweight. Mature cattle, donkeys, horses and mules can be considered as 1 TLU each, while small ruminants (sheep and goats) and calves can be taken as 0.2 TLU.

To estimate future water demand of a community, a rule of thumb is to increase the actual water requirement by 50% to allow for the anticipated population growth and increased per caput use.

Depending on the estimated water consumption figures for people and livestock in a certain area, the water requirement for a month or year can be estimated using the following formula (Astatke, 1984):

$$R = (1 + E) \, . \, D \, . \, X \, (Y \, . \, y + Z \, . \, z)$$

where: R = domestic and livestock water requirement in litres per year.

E = extra allowance for population growth and increased consumption, usually taken as a 50% increase or 0.5 in the equation.

D = number of days for which the stored water supply is needed.

X = number of households using the water.

Y = average number of people in a household.

y = average daily water consumption per person in the area.

Z = average number of livestock units (TLU) per household.

z = average daily water consumption per livestock unit (TLU).

3. PRELIMINARY SURVEYS

Once a pond excavation project has been justified in terms of the need for an improved water supply and the availability of sufficient labour to carry out the work, then suitable pond sites must be selected. Suitable pond sites are those that are accessible to consumers; where the soils are friable, easy to work and have a low permeability to minimise seepage losses; and where the catchment area is large enough

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to provide sufficient runoff to recharge the pond during the main rainy season. In some locations it may also be possible to have some recharge during the short rains, in years when they occur. The area must also offer a suitable location for an outlet to discharge surplus water safely when the pond is full. Aerial photographs (if available) and field visits to the area should be the basis of preliminary site selection. It is essential that members of the PA are involved in selecting their pond site(s).

3.1 Aerial photography and field visits

Aerial photographs at a scale greater than 1:20 000 (such as 1:15 000) are sufficiently detailed to be of use in the preliminary selection of pond sites. They provide information regarding the distribution and number of households and the location of existing watering points. They can be used to identify likely catchments for pond construction in terms of catchment area, topography and vegetation.

It is not possible to obtain information regarding soil characteristics from aerial photographs, so field visits are essential to determine whether the soils are suitable for pond excavation. In many instances up-to-date aerial photographs will not be available and site selection will have to be based entirely on field visits. Ground surveys should be used to verify any information obtained from aerial photographs, and to provide supplementary data about the catchment and the soils.

The following criteria should be used for the preliminary selection of pond sites based on aerial photographs or field visits:

Proximity to the households. As the pond is to be used for domestic purposes and livestock watering, it should be located within easy reach of the consumers (both human and animal). The majority of households should ideally be within a 2-km radius of the pond. Where possible, the distance to the pond should be less than the distance to existing water sources for most users.

Site topography. The pond site should be on gently sloping ground (less than 2%, or 1:50 slope) to simplify construction and minimise erosion. Also, the storage ratio – the volume of water stored to the volume of earth excavated – is more favourable for ponds constructed on gentle rather than steep slopes. The land above the pond should not be level but should slope gently, otherwise runoff will not flow into the pond. The site should be at least 30 m away from the nearest stream, so that it does not interfere with the natural drainage of the valley and to avoid erosion.

Catchment size. The catchment area should be large enough to provide sufficient runoff to fill the pond each year. On the other hand, it should not be too large otherwise the risk of erosion will be very high as a result of concentrating a large volume of runoff in the grassed outlet. (See Section 3.2 for more details).

Vegetation of the area. The area above the pond should be grassed to minimise the rate of siltation of the pond. Grass acts as an efficient silt trap by reducing the rate of runoff and causing deposition of the sediment load before the water reaches the pond. The site itself should be on grazing rather than on arable land, since the latter is more valuable and limited in extent, and is less likely to be assigned by the PA for pond construction. Severely eroded areas should be avoided, as a pond in such a site would quickly fill with sediment and would need frequent desilting. The site should also be free of surface hindrances such as tree roots, boulders or a large number of stones.

Outlet location. When the pond is full, excess water will overflow at the lowest point in the rim. The site should be an evenly sloping, grassed area so that excess water will spread out and flow safely downhill

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into a natural drainageway. During excavation an embankment of dumped soil will go up on the downhill side of the pond. This may prevent excess water from flowing directly downhill, but there should be a natural overflow in a depression to one side of the pond. If the natural depression forming the overflow is disturbed during excavation, it must be planted with suitable grass species to protect it from erosion.

Grass species suitable for medium altitudes include *Chloris gayana* (Rhodes grass), *Cynodon dactylon* (Star grass), and *Panicum coloratum* (Guinea grass). For higher altitudes (above 2200 m) *Pennisetum clandestinum* (Kikuyu grass), *Dactylis glomerata* (Cocksfoot) or *Lolium* species may be more suitable. It is always preferable to use the seeds or shoots from grasses that grow well locally rather than importing exotic species which may not be suited to the environment.

3.2 Catchment hydrology

In addition to the data obtained from aerial photographs and field visits, further information is required on the hydrological characteristics of potential sites. The amount of rainfall and its distribution, runoff characteristics, incidence of waterlogging and other relevant data about the site should be determined. The amount of rain falling directly into the pond and the runoff volume (water yield from the catchment) should be estimated to ensure that there will be sufficient water to fill a pond of the required capacity.

Part of the rain falling in a catchment is immediately lost by evapotranspiration, part infiltrates into the soil, part is held in depressions in the ground, and the remainder becomes runoff. In estimating the volume of runoff from a catchment it is necessary to determine the frequency and duration of rainfall and to estimate how much of the rain becomes runoff. The rainfall–runoff relationship is influenced by rainfall characteristics (intensity, duration and distribution), catchment characteristics (size, shape, drainage density and topography), soil characteristics (infiltration capacity, permeability, texture and depth), and by land use and vegetation cover.

The total volume of runoff is needed when estimating the catchment size required to provide sufficient runoff to fill a pond. Total annual runoff is referred to as water yield. The minimum water yield (least flow over a number of years) should be used to determine the catchment area needed to ensure that the pond fills even in a dry year. If water needs equal the pond capacity, then shortages of water will occur when the annual water yield is not sufficient to fill the pond. If storage is greater than water needs, then some water can be carried over to a dry year.

The following equation can be used to estimate the amount of runoff:

$$Q = P - L$$

where Q is runoff, P is rainfall, and L are losses caused by evapotranspiration and infiltration through the soil.

The losses will vary for each storm according to the amount of rainfall and the amount of moisture which can be absorbed by the soil. Infiltration is the entry of water into the soil. It may be limited by any restriction to the flow of water through the soil profile, such as an impermeable layer. Infiltration rate depends on soil type and its moisture content, the vegetation cover and rainfall intensity. Initially during a rainstorm the infiltration rate equals the rainfall rate and there is no runoff. The soil becomes progressively saturated and surface sealing occurs. Consequently the rate of infiltration decreases. As the infiltration capacity of the soil falls, the rainfall rate exceeds the infiltration rate and runoff is generated. The infiltration capacity reaches a constant value when the soil becomes saturated. This value is related to the texture of the soil.

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Estimates of runoff depend on the availability of rainfall and streamflow records, and the longer and more reliable the records the more reliable will be the estimates. Detailed records will often not be available, in which case the following method can be used to estimate the required catchment size (assuming that the area above the pond is grassed and has clay or clay loam soils with a low infiltration rate).

Assume that during the first month of the rainy season runoff will be negligible (until the soil becomes saturated), and that during the rest of the rainy season an average of 30% of the rain will form runoff. If, for example, the rainfall during the remaining 2 months of the rains is 450 mm, then 150 mm (30%) of this will form runoff. If the desired pond capacity is 9000 m^3, the catchment area required (that which contributes runoff directly into the pond) will be 6 hectares (60 000 m^2 x 0.15 m = 9000 m^3). Even when the soil is saturated the amount of runoff will vary (20–80%) for each storm according to its intensity and duration. The value of 30% is arbitrary, and if more information is known about the proportion of rainfall forming runoff, then such data should be used instead.

In Ethiopia the rainy season is characterised by high-intensity rainstorms, and once the soil is saturated the pond is likely to be filled to capacity by the next heavy storm.

If the catchment area that contributes runoff directly into the pond is found to be too small, diversions can be made to direct more runoff into the pond to supplement that which flows in naturally. On the other hand, the catchment area must not be too large so that the outlet for excess water can be kept to a reasonable size. A maximum catchment area of 50 hectares is suggested.

Where more detailed rainfall records are available, more accurate methods of estimating runoff volumes can be used. The US Soil Conservation Service developed a formula for calculating runoff from individual storms, known as the Curve-Number method. This formula can be used to estimate runoff from either an average storm or the daily rainfall, though it should be used cautiously as it was developed for different environmental conditions. It does, however, give an idea of the total runoff that can be expected.

Curve-Number method to determine runoff volume

Curve-Number formula: $$Q = \frac{(I - 0.2S)^2}{I + 0.8S}$$

where: Q = surface runoff (mm)
I = storm rainfall (mm)
S = catchment storage or the greatest amount of rainfall (mm) that can soak into the soil during the storm.

Some values of catchment storage (S) are given in Table 2, where an allowance is made for the different storage capacities of different soils and it is assumed that if storms occur in quick succession, the soil will not have time to dry out in between. Intermediate values of S can be used.

Table 2. *Values of catchment storage (S) for runoff estimation using the Curve-Number method.*

Soil type	Number of days since last storm that caused runoff		
	5+	2–5	0–2
Good permeability (e.g. deep sands)	150	75	50
Medium permeability (e.g. clay loam, sandy clay loam)	100	50	25
Low permeability (e.g. clays)	50	25	25

Source: Hudson (1975).

The relationship between runoff and rainfall is illustrated in Figure 1 for various values of catchment storage.

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4. DETAILED SURVEYS

4.1 Soil survey

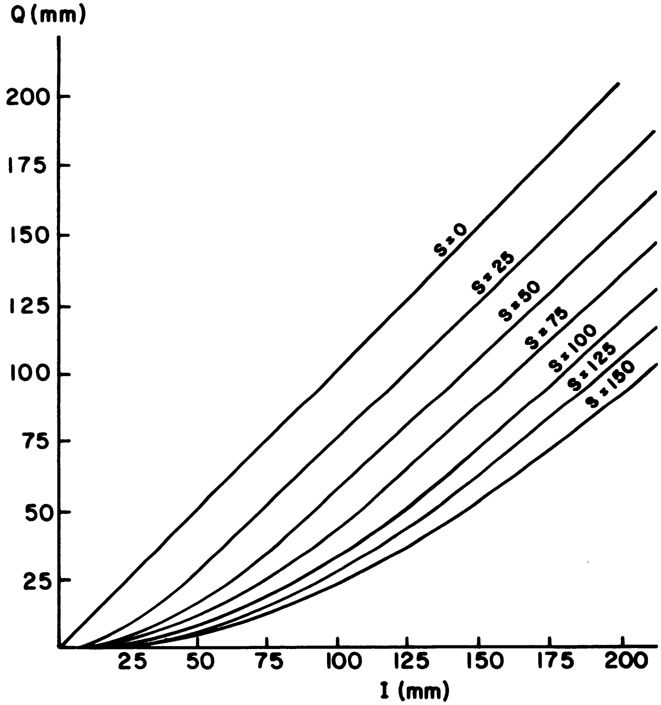
The preliminary surveys described above should have identified one or more potentially suitable pond sites. A more detailed soil survey is now required of each pond site, in order of preference by the PA, until a suitable site is confirmed. A technician with a reasonable knowledge of soil science plus two assistants will be needed for the soil survey. The equipment required for soil survey is listed in Appendix C.

The soil survey should determine whether the soil textures at the selected site are suitable (clay, silty clay or sandy clay) and have a low permeability and a friable nature to a depth of at least 3 m. A hardened layer, or soil with a very high clay content (more than 60%), will reduce the workability of the soil and significantly reduce the excavation rate of the oxen. On the other hand, if the soil has a clay content of less than 30%, especially below the top 1 m, it will have high permeability and the site should be rejected because water losses by seepage will be excessive.

A 20-m grid (smaller spacing if the soils are very variable) should be laid out over the pond site and soil samples taken from each grid point using a soil auger (Figure 2). A soil auger with extension rods should be used to permit sampling to a depth of 4 m or more – at least 1 m below the desired pond depth. Any changes in consistency and texture, and the depth at which they occur, must be recorded.

There are several types of soil auger, as illustrated in Figure 3, but all are designed for use by one person only. The auger should be turned three times while pushing it into the soil to ensure that a clean sample is obtained from a certain depth and is not mixed with other soil layers. The auger should then be pulled out of the ground; if it is very difficult to extract, it can be turned round twice in the other direction to loosen it. Soil samples should be laid out neatly in the order in which they are removed from the auger hole (Figure 4). The soil sample should be taken from the bottom third of the auger mouth, as the rest will be mixed with soil originating from higher soil layers.

Figure 1. *Relationship between runoff Q (mm) and rainfall I (mm) for various values of catchment storage S (mm) using the Curve-Number method.*



The soil texture should be determined using hand-texturing. Where survey staff are not familiar with this procedure, samples should also be taken. They should be collected, clearly labelled (site, location on the grid and depth) and sent to a soil laboratory for textural analysis. The hand-texturing method is described in Appendix D.

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Laboratory results should be compared with field assessments until the staff are confident of making reliable estimates of texture in the field. The soil texture is important in selecting a site, as it influences both the feasibility of pond excavation and the water-holding ability of the completed pond.

If a 3-m depth of clay, silty clay or sandy clay soil has been confirmed throughout the site with no hindrances such as stone layers or hardpans, the site should be suitable for pond construction. If the clay content is thought to be rather low (less than 30%) but the site is otherwise ideal for a pond, a soil permeability test should be conducted to determine

Figure 2. *Grid layout for soil survey.*

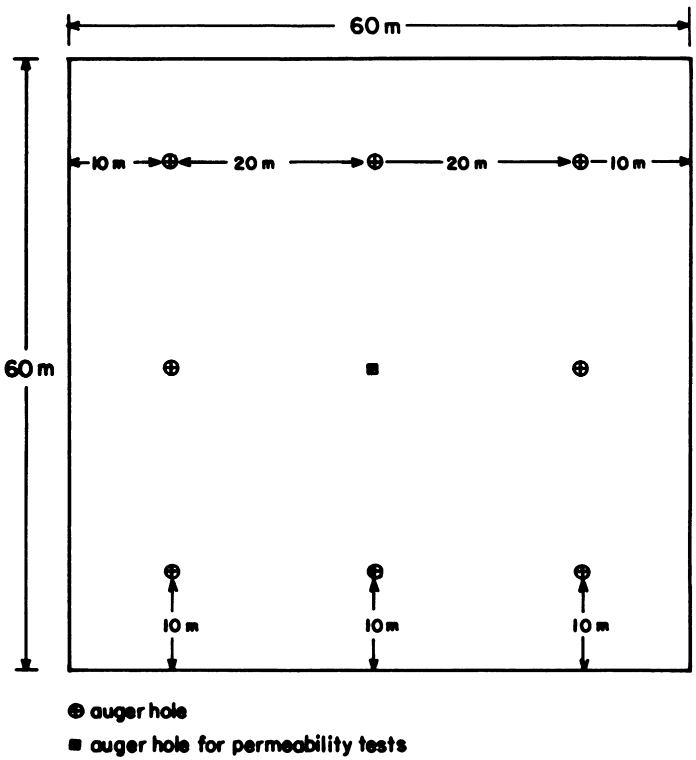


Figure 3. *Soil auger types.*

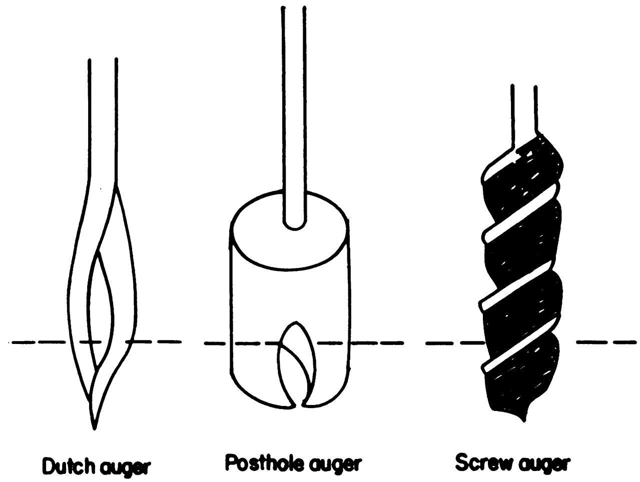
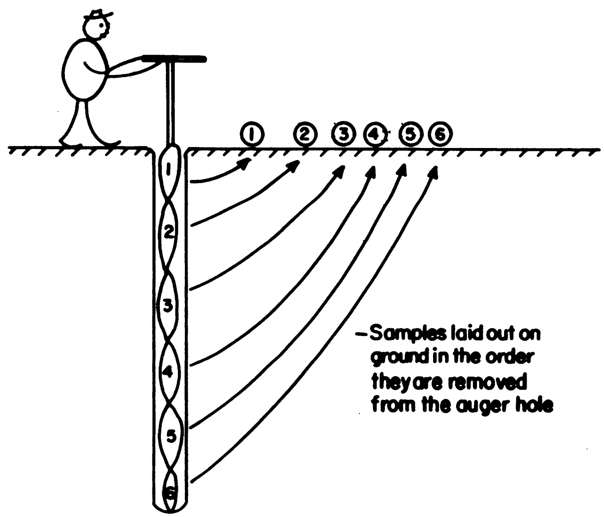


Figure 4. *Laying out soil samples during augering.*



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whether or not a pond in such soils would hold water satisfactorily. If the hydraulic conductivity (K) – a numerical measure of soil permeability – is sufficiently low (K = 0.01 – 0.001 m/day), then seepage losses will not be excessive.

In the Ethiopian highlands high groundwater tables are exceptional (or only present during the rains), so field measurements of soil permeability should be those for use in non-saturated soils. The simplest and most appropriate test used to assess permeability is "the inversed auger-hole method". If a water table is present (in the top 4 m) and the ground is saturated, then the auger-hole method should be used. Further details about the determination of soil permeability are given in Appendix E.

An indicative time schedule for selecting pond sites is given in Table 3.

4.2 Estimated water losses

Water losses from a pond include evaporation and seepage through the soil. Evaporative losses from an open water surface depend on the surface area of the water, daily temperature, relative humidity and wind velocity. Seepage losses vary according to soil type (texture and structure), the surface area in contact with the water and the depth to the water table. Deep ponds are preferable to shallow ones as they offer less evaporation area for a given volume of stored water. The minimum recommended depth of water for the full pond is 3 m. Evaporative losses will be greatest when the pond is full, as the surface area of the pond is greatest at this time.

Satisfactory estimates of expected evaporative and seepage losses can usually be made using unsophisticated techniques. The following should be used as guidelines for determining minimum pond capacities where more information is not available. For ponds excavated in soils with a relatively low permeability (e.g. clay loam to clay textures) in highland areas (>1500 m a.s.l.) the total annual requirement should be increased by 40–60% to allow for seepage, evaporation and non-usable water[3]. For ponds constructed on clay loam soils at low altitudes where ambient temperatures are relatively high, an allowance of 60% of total annual needs should be made for these losses. For ponds constructed on clay soils where temperatures are lower, an allowance of 40% extra will be sufficient. A sample calculation to determine required pond capacity is given in Appendix A.

There are several methods for calculating evaporative losses, but not all of them can be applied in Ethiopia because the necessary data are not recorded at most meteorological stations. An outline of the methods available and their suitability is given in Table 4. A satisfactory indication of evaporative losses can be obtained from open-pan evaporation measurements.

Table 3. *Indicative time schedule for site assessment.*

Procedure	Time period
1. Aerial photograph interpretation	1–2 weeks
– initial site selection and map production	
2. Field visit	1–4 days/site
– to assess suitability of PA and to find a suitable site	
3. Soil survey (3 men)	
– auger holes	1–4 days/site
– permeability test	3 days/site
Total time	2–4 weeks

[3] Non-usable water is that which is not available for use: for instance, the final 30 cm or so of water at the bottom of a pond which has a very high silt content, or the bottom metre of water where the pond is stocked with fish.

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Table 4. *Methods of calculating evaporation.*

Method	Required data	Applicability
Penman's formula	Incoming radiation or sunshine hours, vapour pressure deficit and wind run	Good estimate but only suitable in exceptional cases because of lack of data
Radiation approach	Mean temperature, mean sunshine hours, wind speed, relative humidity	Recommended if data available
Thornthwaite's method	Mean monthly air temperature and latitude	Simple method, data readily available; useful estimate
Pan evaporation	Pan evaporation	Useful as an indication

Monthly average potential evapotranspiration (PE)[4] values and other climatic data for 40 stations in Ethiopia are presented in Appendix G. The areal variation of average annual PE rates in Ethiopia is shown in Figure 5. The figure was drawn up from PE rates calculated using Thornthwaite's method for 67 meteorological stations. The PE rates are seen to be closely related to altitude and air temperature.

Seepage losses are between 1 mm/day and 10 mm/day for soils with a high clay content. At ILCA's pond in Debre Berhan seepage losses through the clay soil were 2.2 mm/day in the first year. This value is expected to decrease as siltation occurs. The inversed auger-hole method for calculating the hydraulic conductivity of soils that are suspected to have rather high seepage rates is described in Appendix E.

[4] Potential evapotranspiration is the amount of water theoretically lost to the atmosphere through evaporation and transpiration if moisture supply is not a limiting factor.

5. DESIGN

5.1 Water balance and pond capacity

By estimating total water requirements and adding total water losses (evaporation, seepage and non-usable water), the amount of soil to be excavated for a pond can be calculated using the following formula:

$$S = \frac{R}{N}(1 + S.E.)$$

where: S = soil excavation required at each pond (m^3)

R = total water requirement (m^3)

S.E. = a factor in the range 0.4 to 0.6 to account for seepage, evaporative losses and non-usable water (dead storage)

N = number of ponds to be constructed.

The water balance of a pond can be calculated to illustrate the rate of depletion of the stored water and the period of time for which the given supply will last. The water balance at a given time can be illustrated by a simple equation:

$$(P + R) - (E + S) - C = St$$

where: P = precipitation falling directly into the pond (m^3)

R = runoff harvested in the pond (m^3)

E = evaporative losses from the water surface (m^3)

S = seepage losses through the pond lining (m^3)

C = consumption by people and their animals (m^3)

St = storage remaining (m^3).

A monthly water budget can be produced in the form of a table showing the initial storage, the recharge through rainfall and runoff, the losses through evaporation and seepage, and the anticipated consumption by the users and their animals. The usefulness of such a budget will depend on the re-

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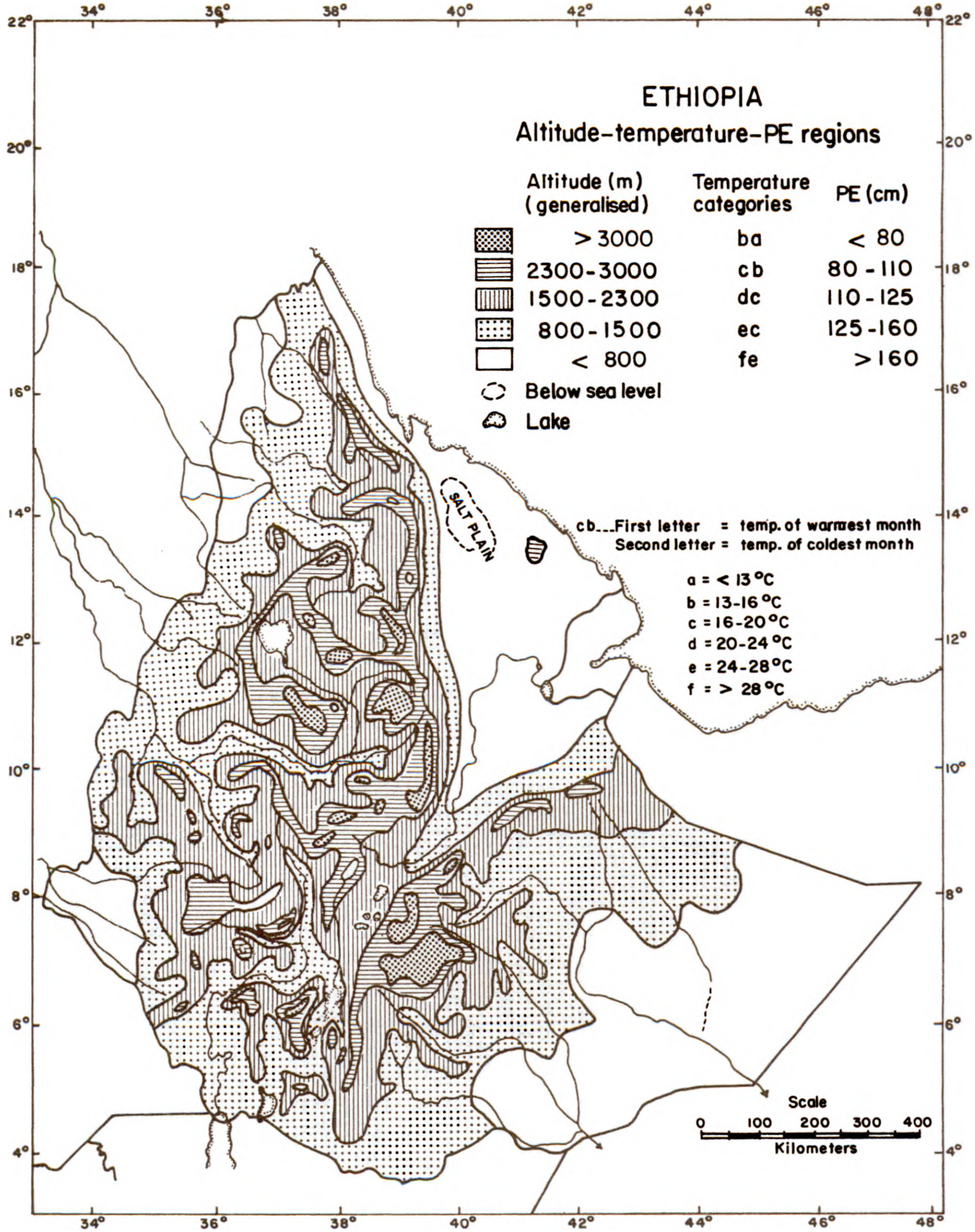
Figure 5. *Areal variation of annual PE rates in Ethiopia.*



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liability of rainfall, evaporation and seepage data used in the calculations.

In most parts of Ethiopia rainfall occurs in a distinct rainy season of 3 to 4 months' duration, so a pond will only be replenished during this period. A budget will be of less use in such areas than in those where rainfall is either bimodal or more evenly distributed.

If the amount of water required by the community is very large, several smaller ponds can be built (capacities of 5000 – 10 000 m^3 are recommended) rather than one pond of larger capacity over the same period. Likewise if the number of oxen is limited, it is preferable to excavate several small ponds in succession (perhaps over several years) rather than one large pond, since fewer oxen will be used each day and hence the interval for resting the working animals will be longer. If possible, a farmer should use his animals for excavating only once a week or less frequently, in order to minimise extra feeding requirements. Also, when completed, the management of smaller ponds will be easier, since each pond will be used by fewer people and livestock.

5.2 Distribution and layout of ponds

The distribution of ponds will be influenced by the settlement pattern in the area and the number of suitable sites to choose from. By increasing the number of ponds the average trekking distance for users can be reduced. Furthermore, desilting can be done in rotation without affecting the pond users. If there was only one pond in the area it would have to be emptied every 4 or 5 years, well before the rains to allow sufficient time for desilting.

As noted in Section 3.1, the pond should be located on relatively flat ground to maximise water storage and to facilitate excavation work. The length of the pond (downslope) should be 100 m at the most (and preferably less), since this is the maximum distance the oxen can be expected to pull a loaded scoop without resting. The width of the pond (across slope) should preferably be similar to the length, but will depend on the number of animals to be involved daily in the work.

The pond entry and exit slopes (upper and lower ends respectively) should be limited to a gradient of 1:3 or less, as steeper slopes impede the movement of oxen. The entry slope for the oxen (upper end) should also be at a low gradient because of the erosion risk. Though the oxen will not be moving across the sideslopes, they should be at a gradient of 1:2 or less as the soils will be saturated and hence unstable when the pond is full of water (see Figure 6). Water should not be allowed to enter the pond from the sides (because their steeper slopes are more prone to erosion), so diversions must be made to ensure that all runoff enters the pond at the upper end.

Normally, runoff should enter the pond along the full width of the excavation. If, however, runoff is concentrated in a natural depression leading into the pond, care must be taken to prevent erosion. Scouring of the sideslope at the entry point should be prevented by riprapping.

A riprap is a pavement of stones laid to prevent the erosion of soil by scouring. Stones of various sizes are placed over the area to be protected in such a way that they interlock and resist movement. The stones should be angular blocks of a dense material resistant to weathering. The riprap should continue below the site at risk to prevent the removal of the bottom stone and thus the failure of the entire section. At the ends of the pavement the stones must be well entrenched in the soil to prevent undermining.

Excavated soil from the pond area will be dumped along the lower end of the pond to build up an embankment. Where possible, the bank should extend for some distance up the sides of the pond (towards the upper end) so that some water is held above the

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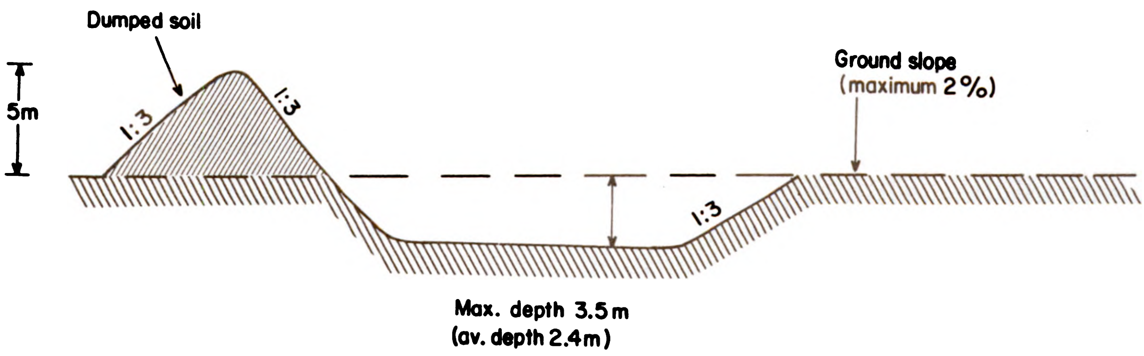
Figure 6. *Cross-section of a pond.*



ground surface during the rains. Even though seepage losses through the bank will be very high, the extra storage obtained above ground level will significantly offset evaporation losses in the dry period immediately after the rains.

The area to be excavated should be marked out with corner pegs. Additional pegs will be needed to mark the area in which the excavated soil will be dumped. Furrows can be dug with the *maresha* between the corner pegs prior to ploughing the entire pond area.

6. IMPLEMENTATION

6.1 Responsibility for the work

Even though an experienced person should be responsible for training the farmers to use the scoops and to solve any technical problems that may arise, the excavation work itself should be supervised and organised by the executive committee of the PA. The committee should decide on such factors as the contribution required by members with only one ox and those without an ox. It will also take action to penalise members who are absent from or late for work and those who do not work efficiently.

Supervision is essential as the work is laborious and time consuming. Unless the maximum possible excavation rate is maintained, progress will be very slow and the farmers will lose enthusiasm. The number of men and oxen employed should be maximised at all times (see Section 6.5) and the number of holidays reduced to a minimum.

6.2 Use and maintenance of implements

Two implements are used in pond construction: the traditional cultivation implement, the *maresha,* and the animal-drawn scoop. The *maresha* is used to break up the compacted soil and the scoops to move the loosened soil to the dumping site. The amount of time spent on breaking up the ground with the *maresha* relative to the time spent scooping will vary according to the friability of the soil and its moisture content. If

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the soil is a light clay loam it will be easy to excavate without much breaking, whereas if it is a dry clay soil it will require a lot of cultivation. At Debre Berhan, approximately 10 hours of cultivation with the *maresha* were required for each 100 m^3 of earth removed.

The final cultivation pass with the *maresha* should be in the same direction as the scooping (lengthwise) so as to minimise the cutting of unloosened soil by the scoops, and hence the load on the animals. To obtain gentle slopes of 1:3 along the ends where the oxen enter and leave the pond, ploughing should start approximately 30 cm closer to the middle of the pond for every 10 cm depth attained. Similarly, for the sideslopes (1:2) ploughing should be reduced towards the centre by 20 cm for every 10 cm increase in depth.

To ensure that gentle slopes are made, soil breaking and scooping should be first concentrated in the central third of the pond. When the design depth is reached in the centre, more soil can be excavated from the sides as necessary to attain the desired slopes.

The metal scoops are designed to suit local oxen with an average liveweight of 250–300 kg. They are made of welded sheet steel, weigh approximately 40 kg each and have a nominal capacity of 0.15 m^3 of soil (Figure 7). The scoop is attached to the yoke by a 3-m length of chain or rope and is guided by the operator using two wooden handles. The scoops can be made at local workshops, where both sheet metal and welding equipment are available. The cost ranges from EB 200–300 per scoop.

The scoop is a robust implement requiring little maintenance and repair provided it is used correctly. From the experience gained in using scoops at Debre Berhan, most breakages occur either on the pivot points or through loosening of the welding on the edge of the drawbar or by breakage of the wooden handles (Figure 7). The handles can easily be replaced by farmers, but when welding is required the scoop must be taken to a workshop with welding equipment. When any damage is observed, the scoop should be taken out of use immediately and repairs made before more serious damage occurs.

6.3 Training of farmers and their oxen

Training of the farmers and their oxen is essential to ensure efficient and successful pond construction. Demonstrations and visits to sites where pond construction is in progress will be beneficial. On-site training should be scheduled when excavation work is first started. Farmers can learn very quickly to handle the scoops: within 2 or 3 hours, provided the oxen are familiar with voice commands.

The handler controls the scoop by raising the handles to fill it with loose soil and by lowering them to ease the drag on the oxen once the scoop is filled (Figures 8 and 9). This technique can be learnt within four or five circuits. Scoop emptying is a more difficult skill to acquire. To dump the soil farmers have to raise the handles of the scoop and tip it forwards using the leverage of the cutting blade while the oxen are moving. If this is done correctly, the soil is spread uniformly in a thin layer on the embankment. If not, it is deposited in a heap which subsequently hinders animal movement and reduces the chances of proper compaction. Compaction is more important for dams than for ponds. After emptying, the handles should first be pulled down sideways so as to move the scoop onto its side, and then pulled towards the operator so that the scoop returns to its normal working position (Figures 10 and 11). The whole procedure can be done while the oxen are still walking, but for inexperienced handlers it is better if the animals stop before the scoop is righted.

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Figure 7. *Design of an oxen-drawn scoop.*

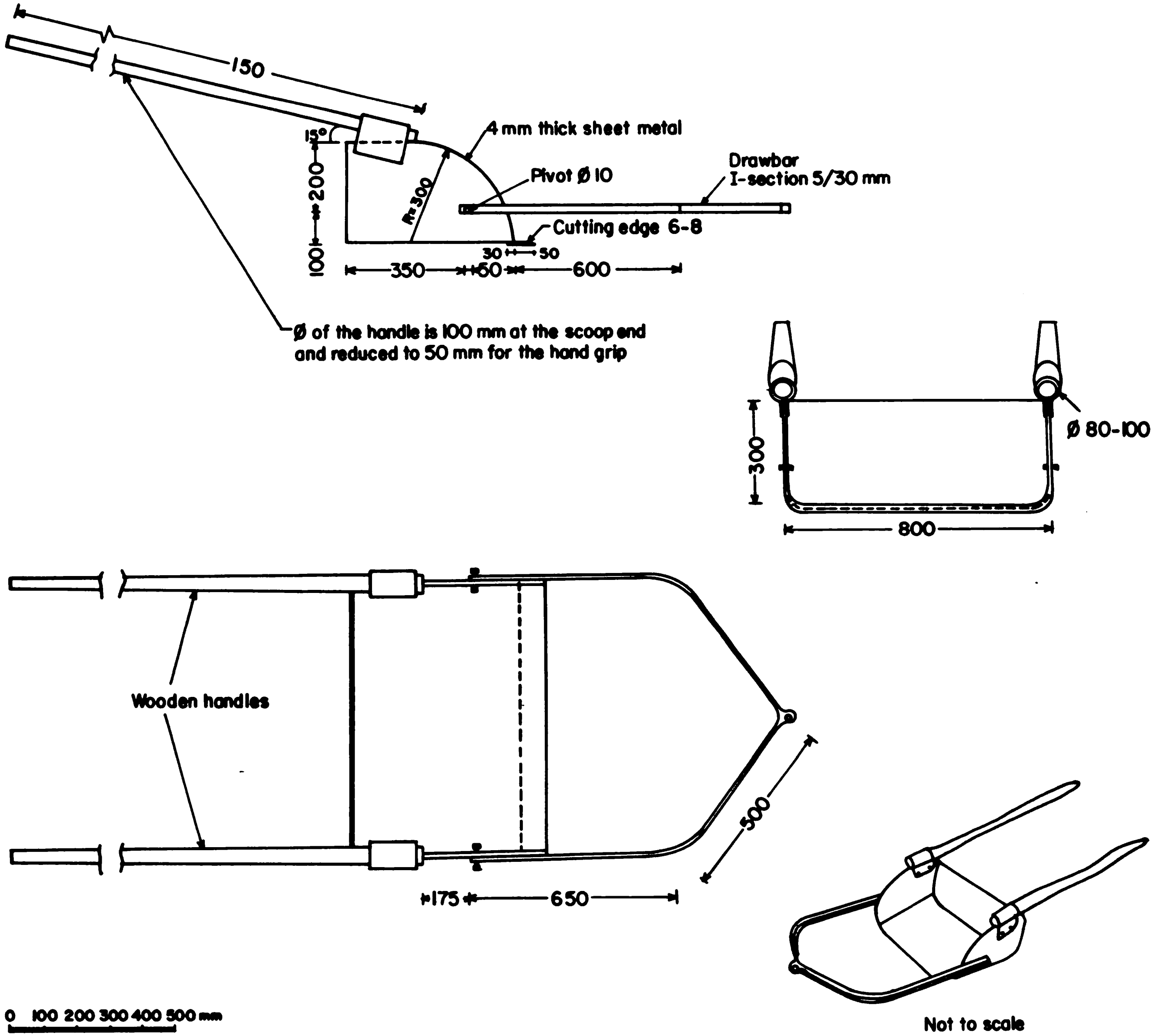

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Figure 8. *Scraping and lifting soil with the scoop.*

Figure 9. *Dragging a full scoop to the dumping area.*

Figure 10. *Emptying the scoop.*

Figure 11. *Righting the scoop after dumping.*

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Most oxen are familiar with voice commands when ploughing with the *maresha,* and they can be used for scooping without any problem. Some oxen, however, have been directed only through manipulation of the implement and are not used to vocal orders. For example, to stop their animals some farmers simply push the tine deep into the soil, while to turn they just pull the handle in one direction to force the animals round. These oxen will need to be trained to respond to voice commands while scooping, since it is not possible to use the scoop in the same way as the *maresha.* When first using scoops some oxen may be frightened by the noise the scoop makes as it runs over the ground. These animals may be nervous and more difficult to handle; they should be managed with the help of an extra person walking in front to calm the oxen until they are used to the sound. There must be no shouting or beating of the animals as this will make them more frightened and will cause confusion.

6.4 The working period

The rains occur at different times of the year in different parts of Ethiopia. In the southern part of the country, from latitude 3° to 5°, the main rainy season is in April and May, while in the rest of the country the main rains occur in June, July and August.

Pond construction should generally be started just after the rains, when the soil is friable and animal feed is relatively plentiful. Another advantage of starting at this time is that work oxen are not required for field cultivation.The construction of new ponds at a latitude of 3° to 5° should therefore be started by the end of June at the latest, and finished by the end of October. For the rest of the country excavation should be started by early October at the latest and, if possible, finished by the end of February, before the small *belg* rains.

Occasionally, ponds will need desilting. This may be once in 4 or 5 years but depends on the rate of siltation. Desilting with scoops should be carried out towards the end of the dry season, when all the water in the ponds has been used. At a latitude of 3° to 5° it should take place in November to February while for the rest of the country desilting should be done in April, May and early June. If there is some water left in the ponds, it should be pumped out by portable pumps sufficiently early in the dry season to allow time to remove all the silt before the rains. If there are fish in the pond they should be harvested before the pond is emptied, or if another pond is available they can be transferred.

6.5 Number of work oxen and their organisation

The maximum number of working pairs that can be employed in the construction of a pond depends on the width of the pond. ILCA found in Debre Berhan that an oxen-pair can work a strip 5 m wide without hindering other working pairs. The width of a pond depends on the size of the area available, the workable soil depth that can be excavated in relation to the quantity of water required, and the topography of the area. It is advisable to keep the width of the pond less than its length, so that the longest full circuit of the pond will not exceed three times its length (100 m maximum). In this case an oxen-pair will drag soil for 1/3 of the circuit distance, while for 2/3 of the distance the scoop will be empty.

The number of work oxen available in an area can limit the number of oxen-pairs used on a pond site each day. In a PA where farmers will construct ponds, the number of working animals to be used should be determined and the capacity of ponds lim-

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ited in accordance with that number. A maximum of 1 day of work per week for each pair of oxen should be maintained. This can be used to calculate the number of oxen-pairs to be used each day (number of oxen-pairs divided by number of working days per week). If 80 working pairs of oxen are found in a PA, the maximum number of animals that can be used per day will be 16 pairs, assuming that no work will be carried out on Saturdays and Sundays. If oxen work only once a week, their owners should be satisfied that they are not subjected to undue stress. As each member of the PA will be expected to work only every seventh day, pond construction should have minimal effect on the routine tasks of weeding, harvesting and threshing, and on social activities.

The number of ponds that can be constructed at any one time by a PA will be limited by the number of working animals and people available (labour is not usually a limitation in rural areas). If most of the working animals (more than 70%) can be utilised effectively on one pond site, it would be advisable to work on one pond at a time, but if the number of working animals is large enough for two ponds, then both should be excavated at the same time. The size of pond that can be excavated over a certain time period depends primarily on the number of oxen available for the work. Based on ILCA's experience in pond construction in Debre Berhan, an oxen-pair can be expected to excavate between 8 and 10 m^3 of soil per day, depending on the soil type and its moisture content (Astatke, 1984; Bunning, 1984).

Oxen must work in a systematic routine so as not to interfere with other pairs. The circuit to be followed is illustrated in Figure 12. The ground should first be broken with *mareshas* and the loose soil then picked up with the scoops and moved downslope to be dumped beyond the lower edge of the pond. After dumping the soil the oxen should walk around the pond area to return to the entry point along the upper end of the pond. They must not walk back over the pond area as this would compact loosened soil. The length of the circuit should be minimised so as to reduce the time and effort expended for each scoop load of soil moved, and to maximise the work achieved per oxen-pair per day.

6.6 Feed requirements of work oxen

The amount of time the oxen are expected to work on a pond has an important influence on their feed requirements. When oxen work on pond excavation for only 1 day a week outside the cultivation season, most of their energy needs should be met by grazing, with some extra straw or hay. On the other hand, if oxen work on the pond for more than 2 or 3 days per week, they will require regular supplementary feeding to maintain condition. From experience at Debre Berhan an extra 2 kg of hay and 3 kg of concentrate per working day, with an average metabolisable energy of 6.5 and 8.2 MJ/kg of dry matter, respectively, should be fed to each working ox. The dry matter content of the hay used by ILCA was approximately 90% while that of concentrate was 80% (Astatke, 1984).

If excavation takes place late in the dry season when grazing is very poor and farmers have finished their stored animal feed, it will be difficult to maintain the condition of the animals. When feed intake is limited, the work output of the animals will be seriously reduced. If the oxen are seen to be losing condition, they should either be worked less frequently or excavation work should be postponed until the next season when sufficient feed is available. The problems related to adequate animal feeding highlight the importance of beginning work as early in the dry season as possible.

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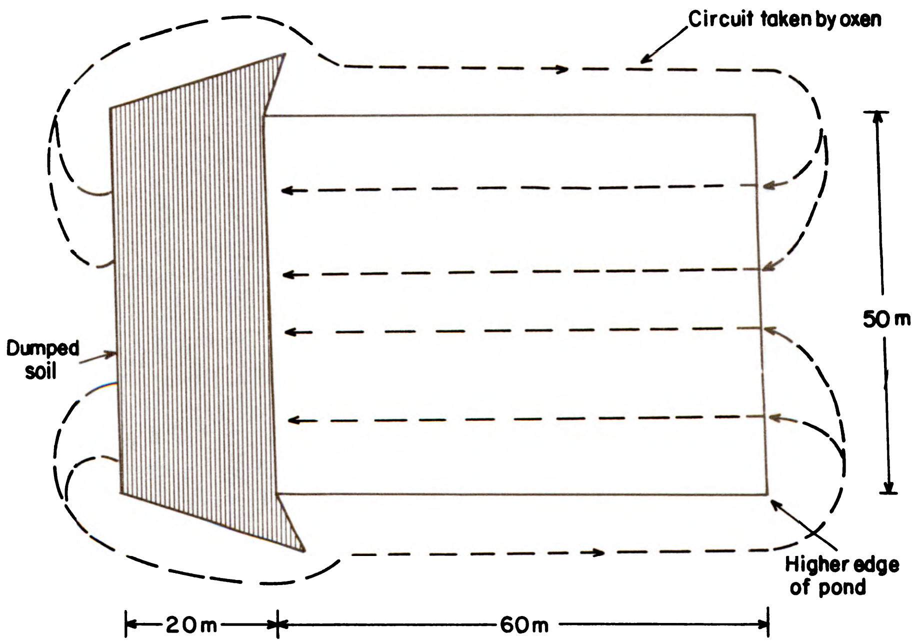
Figure 12. *Circuit taken by work oxen.*



7. MANAGEMENT OF COMPLETED PONDS

7.1 Protection of completed ponds

When excavation is finished the embankment (dumped soil) must be sown with suitable vegetation to prevent the loose soil from being washed back into the pond. Fast-growing grass species that are well adapted to the area are recommended (see Section 3.1).

Once a pond has been completed there are certain precautions that have to be taken by the PA to prevent pollution of the water and minimise the health risks associated with water-related diseases. Some of the possible risks include liver fluke infestation of animals, bilharzia (schistosomiasis) which can infect both people and animals, as well as malaria and other mosquito-borne diseases.

Liver fluke (*Fasciola hepatica* or *F. gigantica*) is a parasite of cattle and small ruminants and is spread via the faeces of infested animals. It requires an intermediate water snail host *(Lymnaea)* for part of its life cycle. Control of this parasitic disease is very dif-

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ficult because of the prolific breeding habits of the snail and the resistance of the cyst stage of the fluke's life cycle. Control methods include chemical treatment with molluscicides, the introduction of fish (e.g. *Tilapia*) or ducks which eat the snails, and fencing of the ponds to prevent animals from ingesting the cysts. The ponds should be fenced as soon as they are completed to minimise the risk of liver fluke infestation.

Bilharzia, or schistosomiasis, is another parasitic disease which infects both people and livestock but is more serious for people. Water is contaminated by the excreta of infected humans or animals which contain eggs. The life cycle of the schistosome trematode is similar to that of the liver fluke, with an intermediate snail host. However, besides being taken in by mouth when drinking, the worms can enter the host through the skin. Control of the snail is an obvious way of eliminating the schistosome fluke and can be implemented by preventing the growth of aquatic vegetation – the habitat of the snail. Vegetation should be removed by cutting or by introducing weed-eating fish. The spread of the disease can also be restricted by fencing off the area immediately above the pond, thereby preventing contamination of the water with excreta.

Shallow water bodies with emerging vegetation are an ideal breeding habitat for insects such as mosquitoes and tsetse flies. *Anopheles* mosquitoes, which carry malaria, a serious and debilitating human disease, breed in and around water sites. To reduce the risk of such diseases the pond should be located at some distance from households and should be kept free of vegetation.

It is advisable to fence the ponds to keep out grazing animals which would contaminate the water. Fencing materials such as barbed wire and wooden poles are expensive. An alternative is to grow hedges of animal-proof vegetation such as sisal, or to use stone walls if stones are in plentiful supply around the site. The stone wall can be built along the sides and the lower end of the pond, but a fence must be used along the upper end and across the spillway to allow water to flow unimpeded into or out of the pond.

Where possible animals and people should be prevented from taking water directly from the pond to ensure that it does not become polluted. Livestock should be watered by lifting water (using buckets, siphons or pumps) from the pond into a drinking trough beyond the fenced area. Direct use of the pond water by people can also be prevented by installing hand pumps or siphons to lift the water. Watering points should be at least 20 m downhill of the pond to prevent dirty water from seeping back into the pond. Washing or swimming in the pond should be prohibited. Figure 13 shows the plan of a completed pond.

7.2 Water quality and use

Even if the above precautions are taken, the water will not be pure because of the way it collects in the ponds. Ponds are filled with runoff water; as it flows over the surface this water picks up organic matter (debris from vegetation or of animal origin), soil particles, micro-organisms and maybe also mineral compounds from fertilizers.

There is some self-purification and improvement of water quality over time in a pond as a result of aeration and the settling of suspended matter. Sedimentation of suspended solids reduces the turbidity of the water, biochemical processes degrade organic matter and many bacteria die off because of lack of food. Nevertheless there will still be some pathogenic organisms, such as *Escherichia coli*, in the pond water; so where possible, the water should be treated for human consumption.

Where there is a plentiful supply of fuel for burning, water should be boiled for 15–20 minutes to dis-

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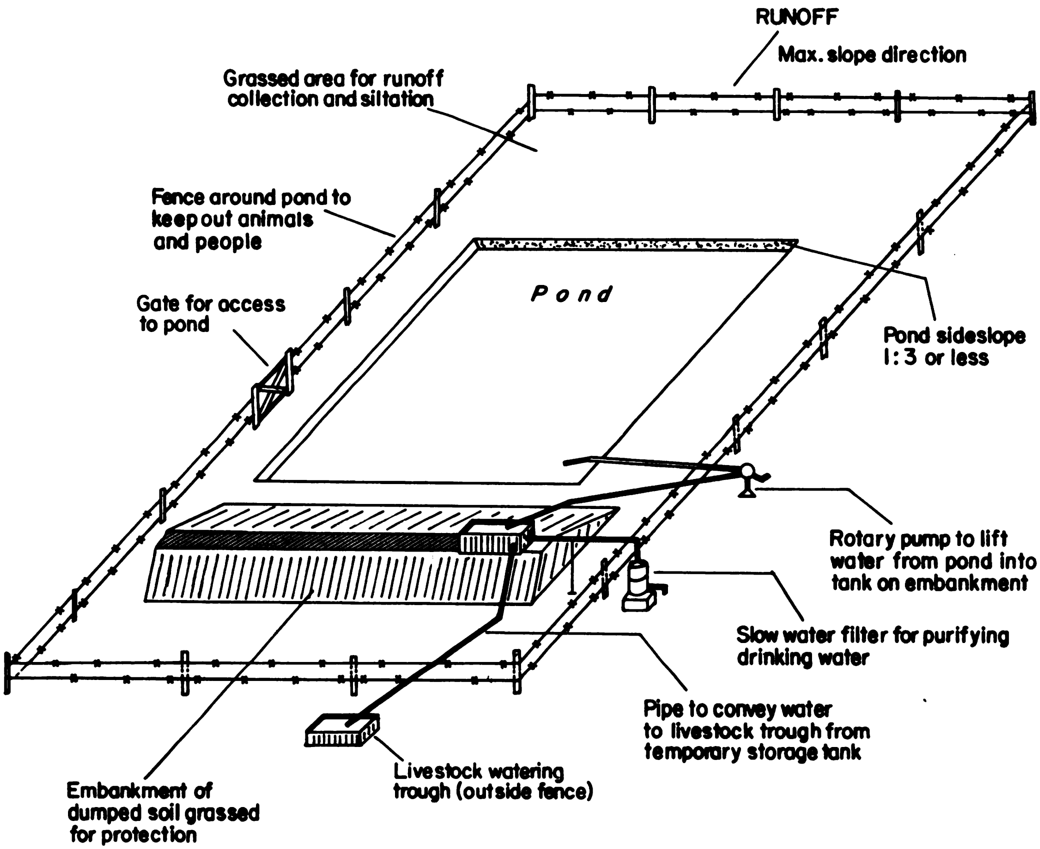
infect it for drinking. Boiling is a very reliable, practical and effective method of treating water, as all forms of micro-organisms are destroyed. The disadvantages of boiling are the resulting flat taste of the water which many people do not like, and the need for fuelwood, charcoal or dung cakes for burning, which may be in short supply.

If funds are available, a slow sand filtration system may be installed at the pond site. This is a reliable low-cost method for the biological treatment of drinking water. A design for a small-scale system using locally available materials is outlined in Appendix F. Slow sand filtration is a purification process in which the water is treated by passing it through a porous bed of a filter medium. During the process the water quality is improved considerably by the removal of suspended and colloidal materials and the reduction of micro-organısms. A well de-

Figure 13. *Sketch of a completed pond.*



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signed and well maintained sand filter will remove the majority of bacteria and the cysts and ova of parasites, as well as most of the substances that cause turbidity, bad taste and odour. The system will not, however, remove all forms of pathogenic organisms, particularly the viruses and very small-sized bacteria. It could be more effective in purifying water if used in combination with chlorination.

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APPENDIX A

SAMPLE CALCULATION TO DETERMINE REQUIRED POND CAPACITY*

Average number of households to use the pond = 50
Average size of household = 4.5 persons
Average water consumption for domestic purposes = 30 l/c/d**
Domestic requirement = 30 x 4.5 x 50 = 6750 l/d

Average livestock population per household = 8.3 TLU
Average livestock water consumption = 30 l/TLU
Livestock watering requirement = 30 x 8.3 x 50 = 12 450 l/d

Losses by evaporation and seepage from pond = 8.8 mm/d***
Losses from a pond of dimensions 60 x 60 x 3 m with sideslopes of 1:3 and 1:2 = 0.0088 x 51 x 54 (dimensions at mid-depth) = 24.23 m^3/day
Required pond capacity = 6.75 + 12.45 + 24.23 = 43.43 m^3/day or 1303 m^3/month
Required pond capacity for dry season (November to May) = 9120 m^3

This is the minimum size, a larger volume of water should be provided to allow for non-usable water. To allow the bottom 30 cm with a high silt content to remain in the pond a further 600 m^3 would be needed giving a total capacity of 9720 m^3.

* Data used from a PA in the Debre Berhan area.
** Increase in consumption with improved supply taken into account.
*** Where evaporation and seepage losses are not known, the formula given in Section 2.1 can be used.

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APPENDIX B

SAMPLE CALCULATION TO ESTIMATE THE VOLUME OF A POND

Prismoidal formula

The amount of soil to be excavated and the maximum capacity of the pond can be estimated quite accurately provided the sideslopes are uniform.

$$V = \frac{D \times [A + (4 \times B) + C]}{6}$$

where: V = volume (m^3)
A = area of excavation at ground surface (m^2)
B = area of excavation at mid-depth (0.5D) in m^2
C = area of excavation at bottom of pond (m^2)
D = average depth of pond (m).

Example
If the dimensions of a pond are 60 x 60 m, depth is 3 m and sideslopes are 1:2 at the sides and 1:3 at the upper and lower ends of the pond, then

$$V = \frac{3 \times [(60 \times 60) + (4 \times 51 \times 54) + (48 \times 42)]}{6}$$

$$V = \frac{3 \times 16\,632}{6}$$

$$V = 8316\ m^3$$

Middle-area formula

A faster but less accurate estimate of volume can be found by the middle-area formula

V = D x A(middle)

where: D = average depth of pond (m)
A (middle) = area of excavation at mid-depth (0.5D) in m^2.

The amount of work required to excavate certain pond capacities can be easily calculated. Some values are given in Table B.1.

Table B.1. *Soil volume to be excavated and work requirements for ponds of different dimensions.*

Pond dimensions (m)	Excavated soil (capacity) (m^3)	Duration of work (days)[a]	
		8 m^3/opd	10 m^3/opd
50 x 50 x 3	5 466	46	37
50 x 50 x 4	6 512	54	44
60 x 60 x 3	8 316	69	56
60 x 60 x 4	10 112	85	68
90 x 40 x 3[b]	7 866	66	53
90 x 40 x 4[b]	9 312	78	62
90 x 40 x 3[c]	8 316	70	56

[a] 15 oxen-pairs scooping x 8 m^3/opd (oxen-pair day) = 120 m^3/day; 15 oxen-pairs scooping x 10 m^3/opd = 150 m^3/day.
[b] Pond aligned with 90 m length across the slope.
[c] Pond aligned with 90 m length running downslope.

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APPENDIX C

EQUIPMENT AND RECORDING FORMS FOR SOIL SURVEY

Equipment

1. Soil auger with extension rods to allow sampling to a 4-m depth. Screw or cylinder (posthole) types of auger.
2. Water for hand-texturing of soil.
3. Notebook and soil survey forms (where available).
4. Tape measure (30 m minimum) and three ranging rods for marking out sample sites on a grid basis.
5. Plastic bags and labels for soil samples requiring further analysis.

For soil permeability tests where soil clay content is suspected to be rather low for ponds:

6. A 50–100 litre water container.
7. Standard (see Figure E.1.) for measuring water level.
8. Metal tape measure.
9. Float for the end of the tape.
10. Wrist watch or stop watch.

Soil survey recording format

Name of recorder: Date:
Name/location of site: Peasant Association:

I. General information (underline relevant description and detail as necessary)

1. Land use: arable/fallow/ pasture (hay)/other:
2. Vegetation: (detail species present)
3. Catchment topography: flat/gentle/rolling/steep
4. Slope of site: $\Delta°/\Delta\%$
5. Surface hindrance: stones/boulders/rock outcrops/other:
   Extent of hindrance: none/little/moderate/extensive
6. Evidence of erosion: runoff/surface crust/siltation/surface channels
   Extent of erosion: none/little/moderate/extensive
7. Water table: yes/no; if yes, depth of water table:
8. Drainage: free/impeded
   Drains: none/few/many
9. Period of waterlogging:

II. Auger-hole samples

At each auger hole describe the following:
Soil structure: loose/granular/moderate porous/compact
Nature of limiting material:
Effective depth:
For each distinctive layer describe the following:
Depth of soil layer:
Colour and mottling:
Soil textural class:
Root and stone content:none/few/many
Moisture condition: dry/moist/wet

III. Additional observations
(record any other relevant factors)

IV. Number of collected samples and their depth
(for those samples taken for further analysis).

Example of soil profile description

Depth (cm)	Colour	Texture	Roots/ stones	Moisture content
0–50	dark brown	sandy clay	many roots	dry
50–125	black	dense clay	few roots	dry, cracked
125–175	brown, mottled	clay	none	moist
175–300	light brown	silty clay	few stones	moist

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APPENDIX D

SOIL TEXTURE DETERMINATION

Manual texture test

Each sample should be hand-textured to determine the textural class – proportion of clay, silt and sand. A ball of soil about 2.5 cm in diameter should be taken and moistened with a few drops of water until it just begins to stick to the hand. The soil is then manipulated as described below; the extent to which the moist soil can be shaped is indicative of its texture. Besides hand-texturing, which is detailed in Figure D.1, a shaking test can also be used to distinguish inorganic silt from clay.

Textural class (see Figure D.1):

A – sand – the soil remains loose and single grained, and can only be heaped into a pyramid.

B – loamy sand – the soil contains sufficient silt and clay to become somewhat cohesive, and can be shaped into a ball that easily falls apart.

C – silt loam – as for loamy sand, but the soil can be shaped by rolling it into a short thick cylinder.

D – loam – because of equal sand, silt and clay content the soil can be rolled into a cylinder that breaks when bent.

E – clay loam – as for loam, the soil can be bent into a U but no further without being broken.

F – light clay – the soil can be bent into a circle that shows cracks.

G – heavy clay – the soil can be bent into a circle without showing cracks, except for vertic clays.

Other features of textural classes:

1. Loam or silt, when dry, gives off a fine powdery dust if scratched or blown upon, but a clay soil will not.
2. Loam, when wet, feels soapy and more or less plastic; when rubbed between the fingers until dry it leaves dust on the skin; clays do not.
3. Clay, when augered, displays shining faces if it has a slightly moist condition; a loam does not.

Shaking test

1. Moisten a pat of clay/inorganic silt slowly until it is saturated.
2. Shake the pat of soil in the palm of the hand; if it is inorganic silt, the pat expels enough water to make its surface appear glossy.
3. If the pat of organic silt is bent between the fingers, its surface becomes dull again.
4. After the pat of inorganic silt has dried, it is brittle and dust can be detached by rubbing it between the fingers.

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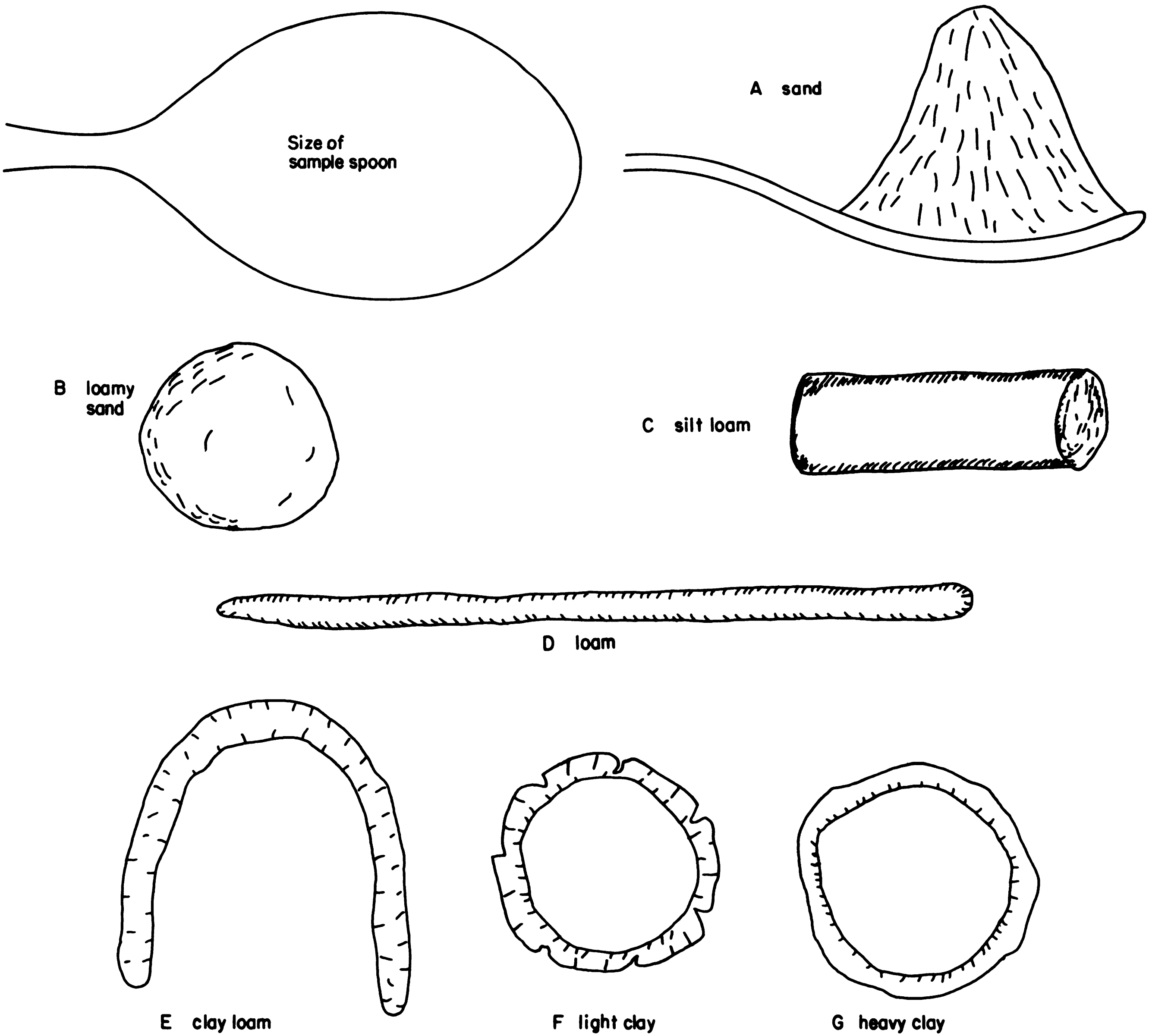
Figure D.1. *Manual soil-texture text.*



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APPENDIX E

DETERMINATION OF HYDRAULIC CONDUCTIVITY (K) FOR NON-SATURATED SOILS

Inversed auger-hole method

The inversed auger-hole method consists of boring a hole to a given depth, filling it with water and measuring the rate of fall of the water level. By gradually deepening the hole and filling it with more water, the hydraulic conductivity (K) value of successive layers can be measured in the same hole. Test holes must be pre-soaked to obtain the more representative percolation rate for saturated soils. The hole should be made with minimum disturbance to the soil; the most appropriate augers are the open Dutch type for wet clay soils or the closed posthole auger for dry soils. Measurements should be repeated up to three times in loam or clay soils to give reliable results.

Method:

1. Dig an auger hole 1 m deep and fill it with water to saturate the surrounding soil (this takes 1/2 – 1 day).
2. Fix a peg near the hole with a horizontal strut as standard, and measure the distance between the standard and the bottom of the auger hole.
3. When the soil is saturated, fill the hole again with water to only 0.5 m of depth.
4. Place a measuring tape with a float attached to the end into the hole and measure the distance of the float to the standard at start, time $t_1 = 0$.
5. Record time taken for the water level to fall by 1 cm (t_2, sec) and repeat 8 to 10 times at each 1 cm (or 0.5 cm) drop in level.
6. Repeat the test at a 2-m depth with water initially filled to 1.5 m.
7. Repeat the test at a 3-m depth with the water filled to 2.5 m.
8. Calculate K using the following formula:

$$K = \frac{1.15r \log[h(t_1) + r/2] - \log[h(t_n) + r/2]}{t_n - t_1} = 1.15r \tan \alpha$$

where: K = hydraulic conductivity (cm/sec)
r = radius of auger hole (cm)
$h(t_1)$ = water level in the hole at time t_1 (cm)
$t_n - t_1$ = change in time (sec)
$ht_1 - ht_n$ = change in water level over time (cm).

9. Plot $h(t_1) + r/2$ against t_1 to obtain a straight line with tangent α. Determine the K value from the graph where $K = 1.15 \tan \alpha$. Discard high initial values to obtain a lower K value than the one calculated using the formula. (See Figure E.2).
10. The K value of the soil should be less than 10 mm/day (<0.00864 m/day or $< 1 \times 10^{-5}$ cm/sec) if the soils are to be suitable for storing water.

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Figure E.1. *Inversed auger-hole method to determine hydraulic conductivity (K).*

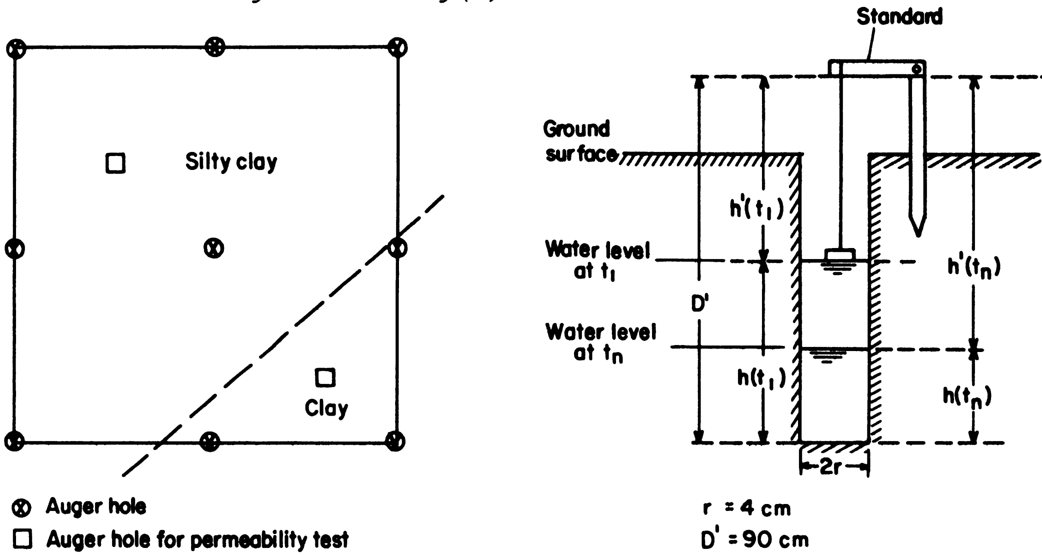
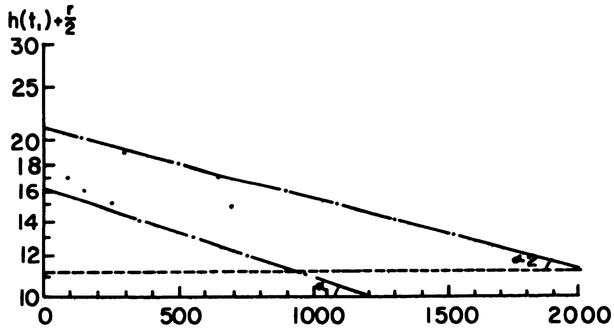


Figure E.2. *Graph of $h(t_1) + r/2$ versus t_1 in the calculation of K.*



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Example

Reading	t_1 sec	$h'(t_1)$ cm	$h(t_1)$ cm	$h(t_1)+r/2$ cm	t_1 sec	$h'(t_1)$ cm	$h(t_1)$ cm	$h(t_1)+r/2$ cm
1	0	73	17	19	0	71	19	21
2	40	74	16	18	140	72	18	20
3	80	75	15	17	300	73	17	19
4	150	76	14	16	500	74	16	18
5	250	77	13	15	650	75	15	17
6	350	78	12	14	900	76	14	16
7	550	79	11	13	1090	77	13	15
8	750	80	10	12	1300	78	12	14
9	975	81	9	11	1520	79	11	13

$$\tan \alpha_1 = \frac{2.0}{10} \times \frac{1}{1200} \text{ sec}^{-1}$$

$K = 1.15 \times 4 \times 0.000167$ cm/sec

$= 0.66$ m/day

$$\tan \alpha_2 = \frac{2.7}{10} \times \frac{1}{2000} \text{ sec}^{-1}$$

$K = 1.15 \times 4 \times 0.000135$ cm/sec

$= 0.54$ m/day

(See Figures E.1 and E.2).

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APPENDIX F

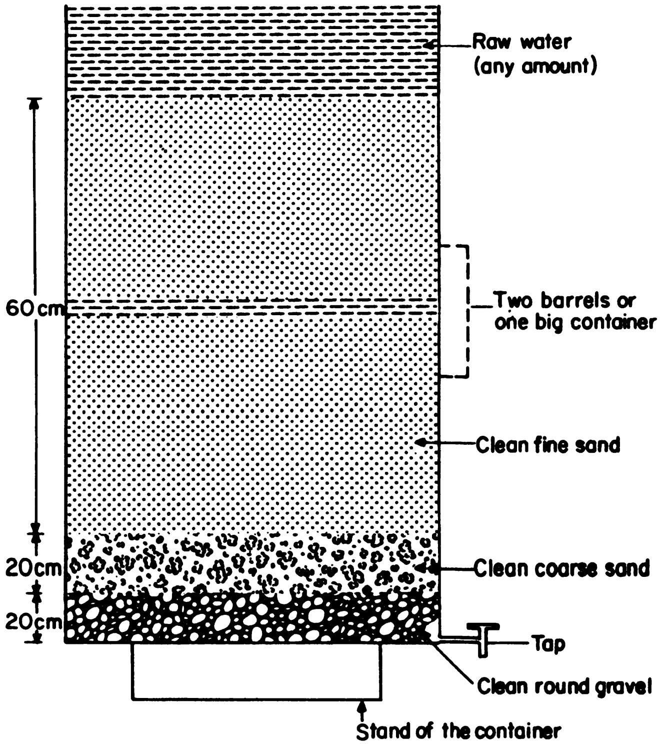
SLOW SAND FILTRATION FOR WATER PURIFICATION

Small-scale sand filtration is a method of treating water for consumption, which can be adopted in rural areas using locally available materials. As water slowly percolates through a bed of carefully arranged sand medium, almost all the suspended and colloidal material is trapped by the top layers of sand. Clear, filtered water is collected at the bottom of the filter medium. Besides sedimentation there is also some biological activity in a slow sand filter, with the growth of micro-organisms in the top layers of the sand. This microbial growth forms a sticky, gelatinous coat which increases the efficiency of the filter medium, provided that the filter is operated continuously. At a certain point the rate of filtration will become very low due to clogging, and the upper layer of sand should be removed for cleaning and then replaced.

A design of a simple sand filter for use in rural areas is shown in Figure F.1. The container should be at least 1.3 m high and 0.5 m in diameter, and it can be made from oil drums, concrete rings or other available materials. A 20-cm layer of clean, round gravel of between 1.5 mm and 5.0 cm in diameter should be placed at the bottom of the container and covered by a 20-cm layer of clean coarse sand. The best sand has hard, round, durable grains free from dirt. Above the coarse sand should be at least 60 cm of fine sand with a grain size of 0.2–0.4 mm. Raw water should filter through the sand at a maximum rate of 1.5 litres per minute. This rate will be exceeded for the first couple of days, until the microbial activity becomes effective.

The filter requires periodic maintenance at an interval varying from a few weeks to several months, depending on the water quality. The topmost layers of sand (5–10 cm) should be removed for cleaning, washed several times and then replaced to maintain the sand depth. Such a device will remove 97% of the bacteria, but it will not remove some of the smaller pathogens such as viruses. Water quality will nonetheless be significantly improved and the water will be much safer for human consumption.

Figure F.1. *A home-made, slow sand filter for water treatment.*



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APPENDIX G

CLIMATIC DATA FOR 40 STATIONS IN ETHIOPIA

PE = potential evapotranspiration (mm) from Thornthwaite's formulae
T = temperature (°C); RF = rainfall (mm)
N = north latitude; m = elevation in m above sea level

Station		J	F	M	A	M	J	J	A	S	O	N	D	Total annual	Average annual
1. Gore	T	19.1	20.0	20.1	19.2	18.3	17.0	16.3	16.6	17.0	17.7	18.4	18.5	–	18.18
8°09' N	RF	39.5	46.9	111.2	136.8	259.5	417.1	334.2	332.2	327.4	191.6	97.2	74.9	2368.5	
2002 m	PE	101.0	94.6	107.1	105.1	102.6	84.8	82.1	82.4	81.6	89.8	93.1	94.1	1118.3	
2. Fiche	T	13.5	13.8	14.3	14.8	14.7	15.1	12.1	12.3	12.0	11.3	10.8	11.2	–	13.0
9°48' N	RF	11.9	20.1	72.4	67.3	46.6	64.0	497.3	407.3	143.4	35.2	6.7	9.5	1381.7	
2820 m	PE	68.0	63.7	77.3	80.3	84.2	86.9	62.6	63.1	59.2	53.0	48.0	51.5	797.8	
3. Wendo	T	16.8	18.4	19.0	18.3	18.0	17.3	17.1	17.3	17.5	17.2	17.1	16.9	–	17.6
6°35' N	RF	104.0	98.0	72.0	243.8	186.0	142.5	190.0	195.0	164.0	299.0	75.5	28.0	1797.8	
1980 m	PE	80.6	86.5	102.0	94.9	95.4	85.5	85.9	87.2	84.8	83.4	80.2	81.6	1048.0	
4. Gimbi	T	23.2	24.3	24.5	23.8	21.4	20.9	18.3	19.0	19.8	19.8	19.1	20.7	–	21.2
9°11' N	RF	26.8	0.0	35.7	105.7	271.1	359.5	302.8	402.1	394.3	99.1	11.2	9.4	2017.7	
1870 m	PE	114.0	111.9	127.7	118.5	110.2	106.0	77.8	85.6	88.7	88.7	80.4	98.0	1207.5	
5. Chencha	T	17.2	17.6	17.4	11.7	14.8	15.9	13.1	12.9	13.5	16.0	17.6	16.7	–	15.7
6°17' N	RF	84.0	41.8	194.1	205.5	215.7	141.0	129.1	91.2	117.9	221.1	41.8	39.1	1522.3	
2700 m	PE	91.8	86.5	94.8	49.0	74.2	80.3	60.4	57.8	60.6	82.4	92.1	89.8	919.7	
6. Debre Tabor	T	15.5	16.5	17.9	18.5	18.8	17.1	16.4	15.7	16.0	15.1	15.9	15.3	–	16.6
11°50' N	RF	8.4	14.8	40.7	50.2	98.2	212.9	486.2	485.5	193.0	48.8	14.8	5.4	1658.9	
2945 m	PE	72.0	74.6	94.8	99.9	108.0	92.2	86.4	78.1	79.6	71.4	76.4	71.3	1004.7	
7. Debre Marcos	T	15.5	16.5	17.3	15.9	14.2	14.4	13.2	13.2	14.1	13.2	13.4	13.3	–	14.5
10°21' N	RF	23.4	17.6	57.0	77.0	61.6	184.4	317.2	317.4	222.5	76.5	7.6	18.1	1380.3	
2411 m	PE	78.0	77.4	94.8	82.4	71.3	72.1	64.8	64.2	67.3	61.2	60.8	61.4	851.7	
8. Nekemte	T	17.5	18.5	18.8	19.4	17.9	16.8	15.4	17.1	18.0	19.2	20.0	20.7	–	18.3
9°05' N	RF	19.8	41.3	58.3	67.4	194.8	404.0	337.0	277.7	214.1	112.7	32.4	22.3	1781.8	
2005 m	PE	85.0	84.6	99.9	105.1	95.1	83.7	70.2	85.6	89.8	103.0	101.9	106.9	1110.7	
9. Megezez	T	7.7	6.7	6.7	7.0	7.0	7.6	6.5	7.1	7.2	5.6	6.0	6.1	–	6.8
9°15' N	RF	42.9	43.0	90.6	41.4	36.5	78.0	197.3	209.1	138.2	11.8	13.3	13.3	915.4	
3700 m	PE	56.0	44.6	50.5	52.5	60.5	59.4	51.8	54.6	53.0	43.9	44.1	44.6	615.5	

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Station		J	F	M	A	M	J	J	A	S	O	N	D	Total annual	Average annual
10. Jimma	T	18.2	19.4	20.2	20.0	19.5	18.7	17.4	17.5	18.1	18.0	16.9	17.2		18.4
7°40' N	RF	28.0	31.3	105.6	184.8	194.6	241.9	219.2	237.8	179.0	51.0	26.2	38.9	1538.3	
1740 m	PE	92.0	91.9	108.2	106.1	110.2	100.7	89.6	88.8	91.8	91.8	78.4	80.2	1129.7	
11. Bonga	T	20.3	21.9	21.7	21.5	20.8	20.0	19.3	17.6	20.5	20.6	20.8	20.2	–	20.4
7°14' N	RF	57.1	66.9	148.4	179.4	243.8	198.1	175.6	181.8	188.8	143.3	56.3	47.2	1689.7	
1720 m	PE	102.0	100.1	113.3	111.2	113.4	106.0	103.7	83.5	104.0	106.1	102.9	101.0	1247.2	
12. Nejo	T	19.7	19.1	22.0	21.0	19.7	18.1	16.7	17.8	18.1	17.7	19.3	20.3	–	19.1
9°30' N	RF	3.4	10.2	14.6	73.7	164.4	227.9	284.0	303.6	306.7	149.9	11.3	11.8	1561.5	
1850 m	PE	101.0	89.2	114.3	111.2	108.0	92.2	78.8	87.7	88.7	83.6	97.0	103.0	1154.7	
13. Addis Ababa	T	15.7	16.9	17.9	17.7	18.0	16.7	15.3	15.2	15.6	15.8	15.3	15.3	–	16.3
9°02' N	RF	16.2	34.8	64.9	87.9	90.4	124.3	276.2	335.8	194.7	26.1	11.7	7.9	1270.9	
2406 m	PE	750.0	774.0	948.0	948.0	994.0	890.0	77.8	77.0	76.5	76.5	70.6	71.3	980.3	
14. Dangela	T	17.8	18.7	18.8	18.7	20.4	18.9	18.5	18.5	18.8	18.4	17.3	16.9	–	18.5
11°17' N	RF	3.7	30.3	10.4	48.9	92.6	193.4	379.6	301.0	236.0	153.8	10.0	9.0	1468.5	
1981 m	PE	89.0	89.2	100.9	100.9	116.6	103.9	102.6	101.7	100.0	96.9	82.3	79.2	1163.2	
15. Agaro	T	20.2	21.3	21.7	22.2	22.3	22.1	19.8	19.5	20.4	19.3	19.0	18.5	–	20.5
7°51' N	RF	39.0	31.1	89.5	103.3	158.8	234.2	223.7	274.1	209.4	123.7	32.7	31.6	1551.1	
1500 m	PE	102.0	98.3	113.3	115.4	121.0	118.7	108.0	107.0	106.1	98.9	90.2	84.2	1263.1	
16. Gidole	T	18.4	19.4	18.9	18.3	17.6	16.7	16.1	16.4	17.4	17.4	17.4	17.0	–	17.6
5°37' N	RF	38.0	47.3	175.3	131.0	199.5	53.0	204.7	107.7	68.2	161.6	53.8	0.6	1240.7	
2550 m	PE	91.8	93.0	100.9	91.8	90.1	79.3	76.3	77.7	82.8	84.5	81.2	81.6	1031.0	
17. Dilla	T	21.3	20.9	21.5	20.7	18.6	17.9	17.8	17.3	17.9	17.4	17.4	18.3	–	18.9
6°25' N	RF	80.9	12.1	132.0	150.0	133.7	136.6	91.8	144.7	184.2	207.3	44.9	34.3	1352.5	
1635	PE	112.2	100.4	113.3	109.1	97.5	90.6	93.3	84.0	88.9	82.4	79.2	91.8	1142.7	
18. Gonder	T	18.4	20.2	21.2	21.1	21.3	18.8	17.4	17.2	18.3	19.2	19.7	18.4	–	19.2
12°37' N	RF	2.2	15.5	16.7	55.1	70.8	188.4	332.5	353.6	140.4	46.9	46.4	19.8	1288.3	
2120 m	PE	90.0	93.7	110.2	110.2	116.6	97.5	85.3	83.4	90.8	98.9	98.0	88.1	1162.7	
19. Giyon	T	16.5	19.3	18.1	19.0	18.7	18.0	17.2	16.8	18.4	18.3	18.9	18.8	–	18.2
8°32' N	RF	20.4	27.3	60.3	74.9	47.9	181.2	257.7	349.3	106.3	89.6	0.0	1.0	1165.9	
2007 m	PE	81.0	93.7	97.9	105.1	108.0	100.7	94.0	88.8	97.9	97.9	98.0	99.0	1162.0	
20. Awasa	T	17.1	20.0	20.1	20.1	19.8	19.5	19.3	18.8	18.8	18.9	17.7	16.2	–	18.9
7°03' N	RF	14.0	43.0	186.0	187.0	112.0	75.0	181.0	75.0	128.0	90.0	57.0	6.0	1154.0	
1760 m	PE	80.0	93.7	106.1	106.1	110.2	106.0	108.0	102.7	97.9	98.9	86.2	71.3	1167.1	

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Station		J	F	M	A	M	J	J	A	S	O	N	D	Total annual	Average annual
21. Bako	T	19.3	21.5	21.2	22.2	20.4	19.7	18.4	18.8	18.7	18.8	19.1	19.0	–	19.8
9°07' N	RF	6.9	19.1	105.9	60.3	84.5	155.4	251.0	249.1	173.9	20.3	06.3	15.0	1147.7	
1640 m	PE	96.0	100.1	111.2	118.5	113.4	106.0	95.0	95.2	90.8	90.8	94.1	94.1	1205.2	
22. Kombolcha	T	16.6	18.1	19.7	20.1	21.0	23.0	20.5	20.4	19.5	18.0	16.8	16.3	–	19.2
11°04' N	RF	32.7	51.4	83.6	77.7	31.9	24.4	301.8	274.9	160.5	27.7	09.5	18.0	1094.1	
1963 m	PE	72.0	81.0	103.0	106.1	116.6	125.1	114.5	113.4	100.0	90.8	70.6	69.3	1162.4	
23. Dodola	T	12.5	14.4	13.7	14.5	13.7	13.1	12.4	13.8	12.1	11.8	11.2	11.9	–	12.9
6°58' N	RF	20.2	9.3	38.0	40.6	61.1	71.8	140.8	145.2	97.7	40.3	11.1	22.9	699.0	
2540 m	PE	59.2	67.9	69.0	75.5	71.0	64.9	61.5	71.5	55.6	53.6	47.5	53.0	750.2	
24. Gobba	T	11.6	12.4	13.5	13.1	13.5	13.5	13.5	13.1	13.0	12.1	11.6	11.1	–	12.6
7°01' N	RF	2.8	29.0	63.9	74.1	69.1	57.9	125.4	95.0	112.0	67.2	17.1	4.4	717.9	
2743 m	PE	56.1	56.7	72.1	69.4	74.2	72.1	74.2	71.4	68.7	60.8	54.5	52.0	782.2	
25. Debre Berhan	T	12.9	14.0	15.7	16.6	17.1	17.9	15.6	16.1	16.4	13.8	13.1	12.1	–	15.8
9°40' N	RF	22.8	8.0	31.4	27.2	36.5	24.5	293.3	269.7	78.3	1.8	6.5	8.0	808.0	
2640 m	PE	56.0	59.2	81.4	90.6	97.2	103.9	84.2	87.7	87.7	65.3	56.8	49.5	919.5	
26. Asosa	T	22.5	23.1	23.9	23.1	22.1	20.2	18.7	18.9	19.4	19.8	20.2	21.1	–	21.1
10°03' N	RF	0.0	5.0	4.0	89.3	76.3	111.3	220.7	203.9	210.6	116.0	8.0	15.4	1060.5	
1640 m	PE	112.0	104.7	123.6	118.5	118.8	106.0	86.4	87.7	93.8	100.0	98.0	104.0	1253.5	
27. Maychew	T	14.8	14.7	16.2	17.3	18.8	20.0	18.4	18.0	17.1	15.1	14.8	14.6	–	16.7
12°47' N	RF	18.6	20.4	67.5	83.9	38.8	12.3	205.9	242.6	84.7	30.0	5.2	7.7	817.6	
2427 m	PE	66.0	60.1	82.4	90.6	109.1	111.3	103.7	101.7	88.7	71.4	64.7	64.4	1014.1	
28. Sire	T	16.3	17.4	18.9	19.6	20.6	19.9	18.4	18.3	18.3	17.3	16.1	18.8	–	18.1
8°18' N	RF	8.5	9.9	63.0	71.1	28.5	70.5	157.8	182.3	193.0	97.3	1.3	3.7	886.9	
1980 m	PE	72.0	75.5	97.9	104.0	115.6	109.2	99.4	98.4	93.8	84.7	69.6	94.1	1114.2	
29. Mendida	T	20.5	21.5	22.5	22.6	21.4	19.6	18.3	18.5	19.2	19.2	19.3	19.5	–	20.2
9°39' N	RF	0.0	0.0	49.4	30.7	75.7	37.2	396.1	310.1	82.8	0.0	0.0	0.0	982.0	
1650 m	PE	103.0	100.1	118.5	118.5	118.8	104.9	94.0	94.2	97.9	97.9	94.1	98.0	1239.9	
30. Abella	T	20.6	20.7	21.3	21.3	20.4	20.3	19.9	19.4	19.9	19.8	19.8	19.3	–	20.2
6°52' N	RF	40.7	35.8	77.3	118.0	75.7	80.5	156.9	103.9	161.2	82.6	22.2	34.5	989.3	
1675 m	PE	107.1	97.7	111.2	110.2	111.3	108.2	106.0	105.0	101.0	103.0	99.0	102.0	1261.7	
31. Gambela	T	25.4	30.0	30.9	29.7	28.0	26.8	26.0	25.9	26.5	26.9	27.4	27.4	–	27.6
8°15' N	RF	3.6	14.7	26.5	76.8	157.4	178.3	233.1	310.0	204.3	105.4	44.0	15.7	1369.8	
450 m	PE	130.0	147.2	172.0	164.8	159.8	146.3	140.4	139.1	137.7	141.8	140.1	141.6	1760.8	

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Station		J	F	M	A	M	J	J	A	S	O	N	D	Total annual	Average annual
32. Burji	T	21.8	23.7	22.2	19.7	18.2	17.7	17.8	18.2	19.3	20.8	20.9	20.3	–	20.1
5°23' N	RF	39.3	32.6	109.0	148.3	130.5	37.0	56.4	25.5	76.5	157.2	36.2	38.6	887.1	
1960 m	PE	112.2	111.6	115.4	97.9	90.1	82.4	84.8	89.3	96.0	108.2	104.0	105.1	1196.7	
33. Kibre	T	19.0	19.6	19.9	20.1	20.1	19.3	18.4	18.5	19.5	19.3	18.3	18.0	–	19.2
5°53' N	RF	21.4	30.5	84.0	201.9	102.1	56.5	48.3	60.3	55.3	168.0	49.7	14.1	892.1	
1750 m	PE	97.9	94.9	105.1	107.1	111.3	103.0	97.5	96.6	103.0	103.0	91.1	89.8	1200.3	
34. Koka	T	19.2	19.2	21.9	22.8	22.6	23.1	20.8	20.7	22.0	20.4	19.6	18.8	–	20.9
8°27' N	RF	17.5	21.2	47.1	61.1	46.4	58.0	223.8	209.8	110.3	29.3	9.1	13.5	847.1	
1580 m	PE	92.0	83.7	113.3	118.5	124.2	124.0	111.2	110.2	112.2	104.0	95.1	87.1	1275.5	
35. Wenji	T	16.6	19.8	22.7	22.9	23.3	23.2	21.0	20.9	21.2	19.5	18.4	18.6	–	20.7
8°20' N	RF	8.5	19.9	61.9	70.1	35.3	67.8	196.5	193.1	102.0	30.3	1.4	9.3	796.1	
1540 m	PE	68.0	89.2	117.4	118.5	126.4	124.0	113.4	111.3	108.1	98.9	80.4	82.2	1237.8	
36. Debre Zeit	T	17.5	18.7	19.9	20.8	20.9	19.7	17.9	18.5	18.3	17.7	16.9	17.4	–	18.6
8°44' N	RF	9.7	14.3	32.5	57.0	16.8	85.5	189.5	188.6	116.1	14.9	2.1	4.3	731.3	
1850 m	PE	83.0	86.5	105.1	109.2	114.5	108.1	95.0	101.7	95.9	88.7	77.4	92.2	1157.3	
37. Nazret	T	18.2	20.2	21.3	21.8	22.0	21.7	20.3	20.6	20.5	19.3	18.7	17.2	–	20.2
8°32' N	RF	0.0	0.0	9.3	13.5	45.5	73.5	163.6	212.3	160.5	45.5	0.0	0.0	723.7	
1131 m	PE	87.0	93.7	113.3	114.3	110.2	117.7	111.2	111.3	106.1	98.9	87.2	76.2	1227.1	
38. Mekele	T	16.2	17.8	19.2	20.8	21.2	21.1	18.3	17.7	18.7	18.2	16.9	16.1		18.5
13°31' N	RF	2.5	0.0	90.0	37.0	1.0	57.0	234.5	211.5	30.5	0.0	0.0	0.0	664.0	
2130 m	PE	72.8	80.1	103.0	111.3	121.0	117.7	100.8	95.0	96.9	90.9	75.1	66.9	1131.5	
39. Moyale	T	24.8	25.2	25.1	22.4	21.1	20.2	19.6	20.0	21.3	21.7	22.2	23.2	–	22.2
3°32' N	RF	7.5	9.7	53.5	227.3	87.4	9.8	9.2	18.0	9.8	148.5	101.0	43.0	724.7	
1200 m	PE	124.4	117.2	129.8	111.2	107.1	94.8	90.1	94.5	103.0	108.2	105.9	116.3	1302.5	
40. Asmara	T	13.4	12.6	15.2	15.4	17.0	17.2	16.0	16.4	16.7	15.5	14.5	14.2	–	15.3
15°20' N	RF	1.5	2.3	12.7	30.6	42.0	38.2	179.2	151.4	27.4	8.3	22.2	3.7	519.5	
2349 m	PE	56.3	48.2	77.3	78.0	99.9	97.2	89.6	88.6	86.7	76.8	65.6	64.0	928.2	

Source: Gamachu (1977).

Stations listed according to Thornthwaite's moisture regions with decreasing moisture index (Im):

$$Im = 100(S - D)/PE \text{ or } 100\,(r/PE - 1)$$

where: S = annual water surplus; D = annual water deficit;
r = annual precipitation; PE = annual evapotranspiration.

Station	Climatic (moisture) region	Moisture index (Im)
1	Perhumid (A)	> 100
2 – 15	Humid (B)	20 – 100
16 – 25	Moist subhumid (C_2)	0 – 20
26 – 40	Dry subhumid (C_1)	–33 – 0

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